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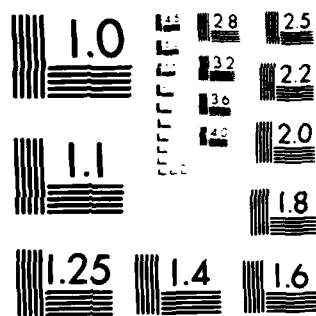
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## FOREIGN TECHNOLOGY DIVISION



THE CALCULATION OF THE AXISYMMETRICAL SUBSONIC VISCOUS FLOW  
FIELD OF ANNULAR DIFFUSERS WITH PREWHIRLING CURRENT  
AT THE INLETS

by

Wang Jiyao and Ling Zhiguang



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# THE CALCULATION OF THE AXISYMMETRICAL SUBSONIC VISCOUS FLOW FIELD OF ANNULAR DIFFUSERS WITH PREWHIRLING CURRENT AT THE INLETS

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## Abstract

The calculation of this class of diffusers has been solved in this paper. From the momentum eq. in the circumferential direction it is proved that the angular momentum component  $rC_\theta$  is constant along the streamline. By using this momentum eq. directly to the streamline iteration procedure for solving the main flow we have overcome the difficulty that the stream surface should be correctly given in advance, as done in the positive  $S_2$  stream surface problem. Then the difference eqs. of the quasi-three-dimensional B. L. eqs. have been got and solved by means of the three-dimensional eddy-viscosity model established by Cebeci, T. and the simple elimination of the other column elements with the main column element.

Moreover, this paper also provides the separation condition and the calculation of a class of energy dissipation coefficient for design of high performance diffusers.

The annular diffuser is an important aerodynamic element. Axial or axial-radial type annular diffusers installed behind the turbine stage can lower the turbine stage's back pressure by using its exhaust gas diffusion disposal. Under the same turbine inlet parametric conditions, it raises the turbine's function capabilities, lowers the residual velocity loss and raises the efficiency of the entire turbine. Because the annular diffuser often operates under inlet flow conditions with certain peripheral and radial velocity distributions, we studied the calculation of the flow of annular diffusers with prewhirling current in order to provide a design and performance calculation method for diffusers with low energy loss coefficients. This has certain practical significance.

This paper still uses the iteration method of the non-viscous main flow and boundary layer to solve this problem.

The obtained convergence solution is the desired flow field.

Below, we will briefly introduce the main features of this method.

In the main flow area (see Fig. 1), the solution of the adiabatic insulation along the streamline isentropic flow field is found with the streamline iteration method. As regards the normal gradient equation used for iteration, this paper only derives it from the axial and radial momentum equation and the circumferential direction momentum equation can prove the relational formula of angular momentum component  $rC_\theta$  is a constant (along the streamline). In the streamline iteration process, we allow the circumferential direction momentum equation to directly participate in iteration. That is, we use the relational formula of the above and its equal value to determine the  $\theta$  angle value on each network point in each iteration but it is not like the problem of the  $S_2$  stream surface which is sought by the stream surface equation  $\theta = \theta(z, r)$  given beforehand. This type of method which uses a circumferential direction momentum equation to directly seek the solution can overcome the  $S_2$  stream surface shape which must be known exactly beforehand when solving the problem of the  $S_2$  stream surface, that is, the basic difficulty of accurately giving the  $S_2$  stream surface equation.  $\theta = \theta(z, r)$  beforehand.

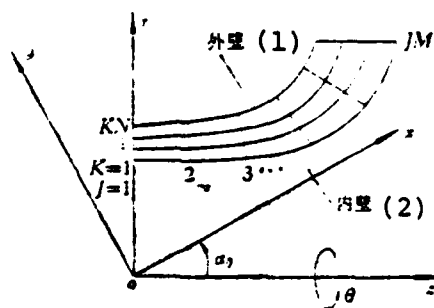


Fig. 1 Main flow iteration network diagram of axial-radial type annular diffuser.

Key: (1) Inner wall; (2) Outer wall

In the boundary layer area, this paper naturally first used the three-dimensional layer's orthogonal curve coordinate system produced after the plane boundary layer's coordinate system rotated  $2\pi$  around the x axis. It can very conveniently be used in coordination with a main flow fixed pseudo-normal network for iteration. Secondly, we used practice to show that the set of equations of the quasi-three-dimensional turbulent flow boundary layer derived from the sealing by the semi-empirical three-dimensional eddy-viscosity model established by T. Cebeci [1] has excellent performance. Aside from this, in the boundary layer coordinate system, after carrying out Falkner-Skan transformation, we also introduced the dimensionless flow function  $F(x, \eta)$  and circumferential direction velocity function  $G(x, \eta)$  based on the specific features of the problem. After changing the boundary layer set of equations into a first order form, we carried out finite difference evaluation based on the mean stable finite difference form of Keller and T. Cebeci (see Reference [2] for details). Within this, when solving the set of large scale linear increment equations, this paper used the simple arranged main element elimination method. When it was necessary to determine the situation of the boundary layer flow transformed from the laminar flow to turbulent flow, this paper viewed the flow field as being formed from the same axisymmetrical flow piece. Afterwards, we used the two-dimensional compressible transformation conditions to determine it.

Calculation example. This paper calculated a total of two examples. One was an axial-radial type diffuser with an inlet prewhirling angle of  $35^\circ$  (Fig. 2) and the other was a conical type diffuser with an inlet prewhirling angle distributed in a large oblique angle of about  $30^\circ$ . Due to limitation of space, we will only draw sectional drawings of the first example's boundary layer velocity as shown in Figs. 3 and 4.



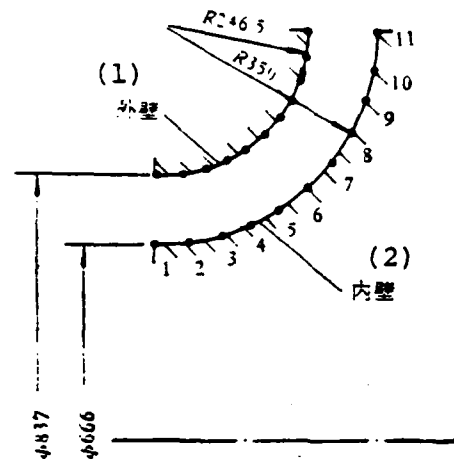


Fig. 2 Axial-radial type annular diffuser.  
Key: (1) Outer wall; (2) Inner wall.

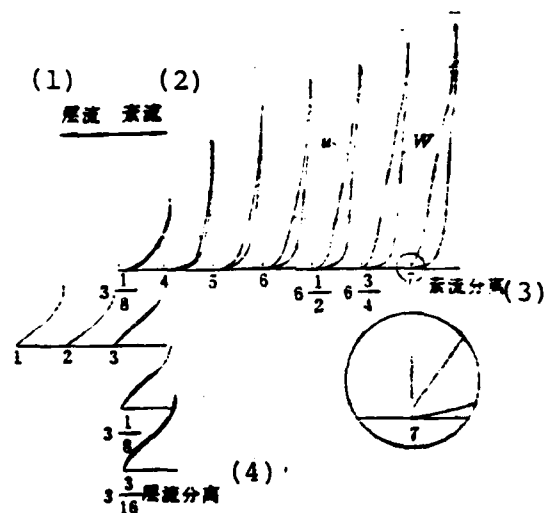


Fig. 3 Sectional drawing of the mean velocity of the axial-radial type annular diffuser's inner wall boundary layer.  
Key: (1) Laminar layer; (2) Turbulent flow; (3) Turbulent flow separation; (4) Laminar flow separation.

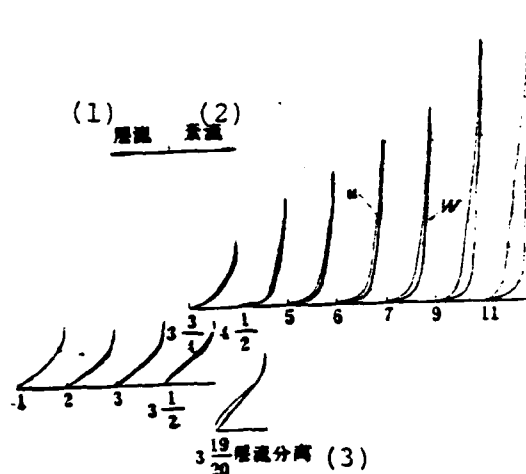


Fig. 4 Sectional drawing of the mean velocity of the axial-radial type annular diffuser's outer wall boundary layer.

Key: (1) Laminar layer; (2) Turbulent flow;  
(3) Laminar layer separation.

It can be clearly seen from the figures that due to the inverse pressure sustained in the meridian plane, the meridian plane's velocity component  $u$  has very fast changes in either the laminar flow region or the turbulent flow region. Laminar flow separation occurs in the  $3\frac{3}{16}$  spot of the inner wall and the  $3\frac{19}{20}$  spot of the outer wall. Even though there is a very strong "eddy viscosity" effect, the turbulent flow region in number 7 spot of the inner wall has flow separation. However, because the circumferential direction's velocity component  $W$  section does not have circumferential direction pressure gradient effects, the changes are very slow and the turbulent flow region is even slower than the laminar flow region. Whether it is the laminar flow region or turbulent flow region, we can obtain the separations of the flows as  $(\partial u / \partial y)_{y=0} = 0$ .

Lastly, by following the deducing procedure of the boundary layer energy integration equation, we can calculate the flow's lost energy  $E_{\text{loss}}$ .

By comparing it with the total kinetic energy  $E_{\text{total movement}}$  used for the inlet, we can obtain a method of calculating the energy loss coefficient  $\zeta_{\text{loss}}$ . Based on this definition, we calculated the size of  $\zeta_{\text{loss}}$  in example 2 of this paper and after comparing it with the test curve, they were basically in agreement.

By using the method of this paper under certain flow conditions, after comparing plans, we can obtain a relatively optimal design plan for a diffuser with a large diffusion ratio and small energy loss. Therefore, this plan can be recommended for use in actual design work.

This paper was read at the Third Annual Conference of the China Engineering Thermophysics Association in Wuxi in October of 1982.

#### References

- [1] Cebeci, T.: "Calculation of Three-Dimensional Boundary Layers, Part 2", AIAA J., 14(1976).
- [2] Cebeci, T. & A.M.O. Smith: "Analysis of Turbulent Boundary Layer". Academic Press, New York. (1974).